

to outbalance all the weighty chemical and physical differences between them."

The nature of the evidence derived from the spectroscope is here quite misrepresented; probably it was not well understood because of its novelty.

I have found that the spectra of magnesium, zinc, and cadmium are the result of three series of harmonic vibrations with similar intervals, the fundamental vibrations of which differ only in pitch. I have made some similar observations with regard to copper, silver, and mercury, aluminium, indium, and thallium, calcium, strontium, and barium, though maps of some of these spectra have not yet been published. I believe that in series of elements such as these, which exhibit gradational differences in properties and in the properties of their compounds, and approximately equal numerical differences in their atomic weights, we are dealing with the same kind of matter in different states of condensation, or in other words, with matter having similarly constituted molecules, the vibrations of which are in the same direction and at similar intervals but with different velocities.

If we attempt to classify beryllium in accordance with the views of Nilson and Pettersson, the elements scandium and yttrium, with atomic weights 44 and 89 respectively, must yield spectra characteristic of the series of which aluminium is the first member, but it is not possible to find a place for beryllium in this group, nor in those to which cerium, lanthanum, and didymium belong; it is, in fact, by a process of exclusion first and selection afterwards that the element falls into the dyad series.

In the position which I assign to beryllium, we can account for it being related, through the properties of its compounds, to magnesium and zinc on the one hand, and to aluminium on the other.

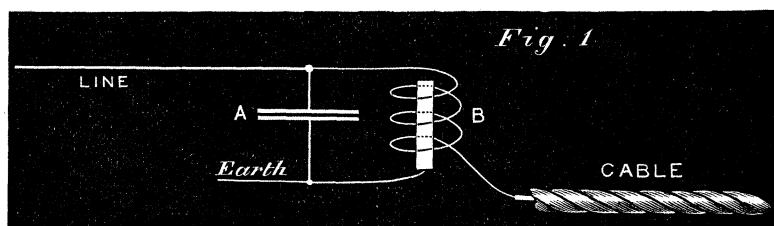
If there is one consideration of greater importance than another which should lead to the determination of the position of an element in a series, it is the mode of vibration of the molecule, and of that we have evidence in the spectrum. When the element is one with a low atomic weight there is no difficulty in interpreting such evidence.

II. "On the Heating Effects of Electric Currents." By WILLIAM HENRY PREECE, F.R.S. Received March 19, 1884.

The production of heat in electrical conductors due to the transference of electricity through them has become a matter of very great practical importance. A knowledge of the variation of the law, due to the dimensions and character of the conductor, is essential for lightning protectors and for the leads of electric lights.

Atmospheric electricity has proved a great danger to insulated wires, subterranean and submarine, and to telegraphic apparatus generally. Not only do the direct discharges of atmospheric electricity enter the wires, but very powerful currents are induced in neighbouring wires when these discharges take place, either between cloud and cloud or between cloud and earth. Various plans have been devised to protect apparatus and wires from these currents. Lightning protectors based on the effect of points, on the facility of discharge through vacuæ, on the low resistance of thin air-spaces to high potential, and on the fusibility of thin wires, have been used.

The most careful and long-continued observations have shown that the survival of the fittest is found, in the use of a thin flat air-space A (fig. 1), supplemented by a fine well insulated protecting wire,



B, of high resistance, wound around a brass rod in connexion with earth. The air-space is obtained by superposing two smooth plane surfaces of thick brass, separated from each other by a space of $\cdot 004$ of an inch, by means of a frame of mica or paraffined paper. It requires (according to the researches of Messrs. Warren De La Rue and Hugo Müller*) confirmed by my own observations made in Dr. Warren De La Rue's laboratory, a potential of 800 volts to strike across such an air-space, and when this is done a path of no resistance, according to Faraday, is established for the atmospheric discharge to flow to earth.† But destructive currents of induction are often produced in telegraph wires, which have not the requisite potential to strike across this air-space, and the element of *time* may enter to force some of the current into the cable or apparatus so as to

* "Phil. Trans.," Part II, vol. 174.

† Dr. De La Rue has been kind enough to repeat these experiments with the following results:—

Air-space.	Potential.
$\cdot 001$ in.	453 volts.
$\cdot 002$ „	659 „
$\cdot 003$ „	824 „
$\cdot 00475$ „	1030 „
$\cdot 005$ „	1030 „

injure it. Hence a protecting wire has been added, which, while it will allow all working currents to pass without retardation, will not allow a current strong enough to damage the cable to flow through without its being fused. It thus acts as a safety valve. The length and dimensions of this wire have not been hitherto determined by any stringent conditions. After having determined the conditions required to give the maximum effect with the so-called "plate protector"* I became anxious to find out the conditions that would give a similar result with the "wire protector."

Now, the very strongest current that can, under any possible circumstances, enter a wire from the working batteries is one of 500 milliampères (·5 B.A. unit current), while atmospheric currents enter the wires of all strengths from 1 milliampère to 30 or 40 ampères, or even more. Therefore, it was desirable to find that wire which would not fuse with 500 milliampères, but would fuse with currents of about 700 milliampères and over.

Hence, I took a source of electricity, which was a large thermopile of Clamond's make, which would give the necessary current, a rheostat by which it was possible to regulate this current to any strength, a Thomson mirror galvanometer which enabled me to measure, record, and regulate every change of current, and a discharger by which I was able to hold, measure, and adjust the wires to be tested.

1. With a given current and a uniform wire of given diameter and given material, the effect, allowing for the cooling effect of the binding screws, was independent of the length, for whether the length experimented upon was an inch, a foot, or a yard, it always fused when the current reached a certain definite strength. The point of fusion was irregular, for it simply depended on some irregularity in the uniformity of the wire, and the weakest link in the chain went.

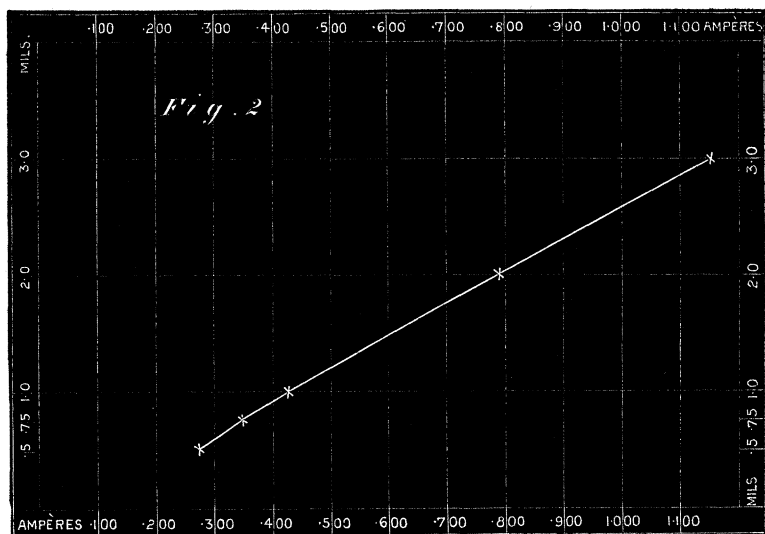
2. Samples of platinum wire of various diameters, each of 6 inches in length, were taken, and the current increased gradually until the wire fused. The results are given in the following table:—

Diameter in parts of an inch.	Fusing current in ampères.
·00050	·277
·00075	·356
·001	·437
·002	·790
·003	1·150

* British Association, 1880.

The above figures are the average of numerous experiments, and they are plotted out in fig. 2.

The general law governing the ratio between the current strength and the diameter of the wire when the latter is raised to a definite temperature, and where radiation is free and unchecked by any athermanous envelope, appears to be that the current should vary as the diameter $\times \sqrt{\text{diameter}}$;* this may be proved as follows.



The heat developed in any cylindrical wire is by Joule's law—

$$H = C^2 R t,$$

where

$$R = \frac{2\alpha l}{\pi d^2}$$

α being the specific resistance, l the length, and d the diameter, then—

$$H = C^2 \cdot \frac{2\alpha l}{\pi d^2} \cdot t = \mu \left(\frac{C}{d} \right)^2;$$

or if we maintain the ratio between the current and the diameter constant, the same amount of energy will be wasted in the conductor.

But the temperature of the conductor is dependent on the rate at which the heat is radiated and conducted away, and when the heat imparted by the current just balances that lost by radiation

* "The Electrical Review," June 24, 1882, p. 454, and Prof. George Forbes, Brit. Assoc., 1882.

and convection, the temperature becomes constant. But the heat lost varies with the surface, and the smaller the surface the less the loss, and therefore the temperature will vary with the diameter. Hence as—

$$H \propto \mu \left(\frac{C}{d} \right)^2,$$

and also

$$H \propto d,$$

therefore

$$\frac{C^2}{d^3} = d, \text{ or, } C = d\sqrt{d}.$$

The results of the foregoing experiments on the current required to fuse wires of different diameters would appear to contradict this law, and to show that the current varies as the diameter, but there are several elements in the method of making the measurements which tend to modify the general law. Platinum wires—especially those of small diameter—are liable to flaws which practically reduce their effective diameter to a great extent; also the larger wires from their greater weight necessarily tend to part asunder at a lower temperature than those which are lighter and on which the strain is less.

3. In thermometric measurements there are only two fiducial points usually employed, viz., the freezing point, and the boiling point, but there are two other points equally well marked, though perhaps not quite so accurately fixed. These are the points of self-luminosity and of fusion. The first point has been determined by Daniell to be $\left\{ \begin{array}{l} 980^\circ \text{ F.} \\ 526^\circ \cdot 6 \text{ C.} \end{array} \right\}$, and by Draper at $\left\{ \begin{array}{l} 977^\circ \text{ F.} \\ 525^\circ \text{ C.} \end{array} \right\}$, and it has been shown by the latter observer that this is true for all substances.

I was anxious to discover whether the law before stated would apply in the case of the production of the lowest visible red radiations by currents. I therefore took several wires of different materials, and of different diameters, but all of the same length, and by observing them in a carefully constructed dark chamber, determined the currents that produced self-luminosity, these currents being measured by finding the difference of potential at the ends of a thick German silver wire (R) whose resistance was $\cdot 0157\omega$, inserted in the same circuit. The results of the experiments, which were very carefully made, are given in the following tables:—

Constant deflection from standard Daniell cell = 9050' (<i>d</i>) through 10,000 ohms.											
$C = \frac{1 \cdot 07}{d \times R} \times D.$											
	Description of wire.	Gauge of wire in mils.*	Area per square inch.	Deflection.	Shunt.	Resistance in coils.	Resistance of shunted galvanometer.	Total resistance.	Equivalent deflection through 10,000 ohms (D).	Observed current in ampères.	Current calculated from the formula $\cdot 14587 \times d \sqrt{d}$.
Copper.	30	·0007066	285	$\frac{1}{1000}$	1,000	512	1,512	4309	23·969	23·969	
	24	·0004523	212	$\frac{1}{10000}$	10,000	5121	15,121	3026	16·832	17·151	
	20	·0003141	163	$\frac{1}{10000}$	10,000	5121	15,121	2465	13·711	13·047	
	18	·0002544	134	$\frac{1}{10000}$	10,000	5121	15,121	2026	11·269	11·140	
	14	·0001539	91	$\frac{1}{10000}$	10,000	5121	15,121	1376	7·654	7·641	
	8	·0000502	113	$\frac{1}{1000}$	1,000	5121	6,121	692	3·849	3·300	

Constant deflection from standard Daniell cell = 9050'.										
Swedish wrought iron.	Description of wire.	Gauge of wire in mils.	Area per square inch.	Deflection.	Shunt.	Resistance in coils.	Resistance of shunted galvanometer.	Total resistance.	Equivalent deflection through 10,000 ohms.	Current calculated from the formula $\cdot 035755 \times d \sqrt{d}$.
60			·002827	330	$\frac{1}{1000}$	5000	5,121	10,121	3340	18·579
40			·001256	345	$\frac{1}{10000}$	5000	51,210	56,210	1939	10·785
20			·0003141	137	$\frac{1}{10000}$	5000	51,210	56,210	770	4·283
10			·0000785	55	$\frac{1}{10000}$	5000	51,210	56,210	309	1·718

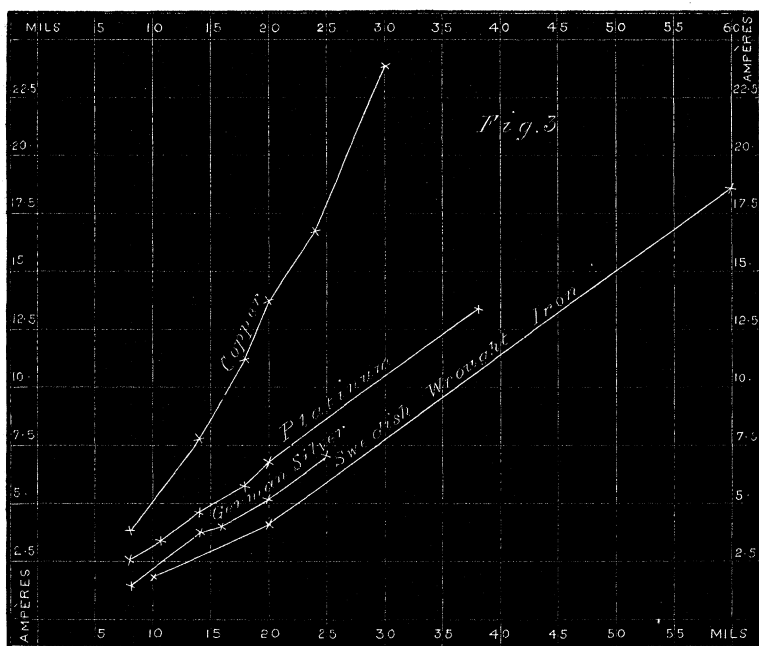
* The mil is one-thousandth of an inch.

Constant deflection from standard Daniell cell=9050'.										
German silver.	Description of wire.		Deflection.	Shunt.	Resistance in coils.	Resistance of shunted galvanometer.	Total resistance.	Equivalent deflection through 10,000 ohms.	Observed current in amperes.	Current calculated from the formula $\cdot 056376 \times d \sqrt{d}$.
	Gauge of wire in mils.	Area per square inch.								
25		·0004908	207	$\frac{1}{96}$	1,000	5,121	6,121	1267	7·047	7·047
20		·0003141	150	$\frac{1}{96}$	1,000	5,121	6,121	918	5·106	5·042
16		·0002010	115	0	10,000	51,210	61,210	704	3·916	3·608
14		·0001539	110	0	10,000	51,210	61,210	673	3·743	2·953
8		·0000502	37	0	10,000	51,210	61,210	226	1·257	1·276

Constant deflection from standard Daniell cell = 12,252'.										
Platinum.	Description of wire.		Deflection.	Shunt.	Resistance in coils.	Resistance of shunted galvanometer.	Total resistance.	Equivalent deflection through 10,000 ohms.	Observed current in amperes.	Current calculated from the formula $\cdot 057465 \times d \sqrt{d}$.
	Gauge of wire in mils.	Area per square inch.								
38		·001134	121	$\frac{1}{96}$	1000 + 488	512	2000	2420	13·461	13·461
20		·0003141	123	"	488	512	1000	1230	6·841	5·140
18		·0002544	104	"	488	512	1000	1040	5·785	4·389
14		·0001539	142	"	88	512	600	852	4·739	3·010
11		·0000950	100	"	88	512	600	600	3·337	2·097
8		·0000502	76	"	88	512	600	456	2·536	1·300

The results are plotted out in fig. 3. It will be seen that the observed and calculated results agree to a considerable degree of accuracy except in the case of platinum, which behaves as in the previous experiments, and is generally found to be irregular in its quality.

These experiments were made upon wires exposed to the air, where radiation is free. I am anxious to repeat them upon wires covered in insulating material and buried in the ground, but I have not been able to do so up to the present moment. The law with reference to such wires has a very important bearing on the size of electric light



leads, for it shows the necessity of making them large enough to prevent the possibility of their being heated above normal temperatures, otherwise points of danger are very easily reached by increments of current.

III. "Spectroscopic Studies on Gaseous Explosions. No. I." By G. D. LIVEING, M.A., F.R.S., and JAMES DEWAR, M.A., F.R.S., Professors in the University of Cambridge. Received March 28, 1884.

Having occasion to observe the spectrum of the flash of a mixture of hydrogen and oxygen fired in a Cavendish eudiometer, we were struck by the brightness, not only of the ubiquitous yellow sodium line, but of the blue calcium line and the orange and green bands of lime, as well as of other lines which were not identified. The eudiometer being at first clean and dry, the calcium must be derived either from the glass or from some spray of the water over which the gases with which the eudiometer was filled had been confined. It seemed incredible that the momentary flash should detach and light up lime from the glass, but subsequent observations have pointed to that con-

Fig. 1

